Western Canada Study of Animal Health Effects Associated with Exposure to Emissions from Oil and Natural Gas Field Facilities

WHAT ABOUT THE CATTLE?

A Study of 33,000 Cattle in British Columbia, Alberta and Saskatchewan

WISSA Western Interprovincial Scientific Studies Association

What About The Cattle?

A study of the effects of oil and gas industry emissions on 33,000 beef cattle in 205 herds across Alberta, Saskatchewan, and northeastern British Columbia has found that higher concentrations of the airborne contaminants studied were not associated with more abortions and stillbirths, fewer pregnancies, and most of the other measures of animal health and productivity examined.

The finding addresses long-standing concerns of cattle producers that emissions from oil and gas facilities, often located on land for pasturing or wintering cattle, increase numbers of abortions and stillbirths, lower pregnancy rates, and contribute to disease in the herds.

Airborne contaminants investigated included sulphur dioxide, hydrogen sulphide, volatile organic compounds, particulates, and polycyclic aromatic hydrocarbons.

These chemicals can be found in airborne emissions from well sites, batteries, compressor stations, gas plants, and other industry field facilities.

Most of the other measures of animal health and productivity investigated, including lesions in immune, nervous, and respiratory systems of calves, and several immunolgical characteristics of calves and yearlings, were not associated with exposure to any of the emissions.

Researchers did, however, find that one or more airborne contaminants were "significantly associated with animal health effects, such as a longer breeding to calving interval, more calves receiving medication, and weakening of some components of the immune system of the cattle.

The most noteworthy association was that cows exposed to the highest concentrations of sulphur dioxide during the last 3 months of pregnancy were more likely to deliver calves that died before they were 3 months old. Between 1 and 2% more calves died in locations with the highest measured levels of exposure as compared to the lowest.

The researchers concluded that this finding could reflect a true effect of exposure to sulphur dioxide, or to an air contaminant or a mixture of contaminants closely associated with sulphur dioxide.

In a parallel investigation of European starlings, an indicator species that shared the same environments as the cattle, no conclusive associations were found between the reproductive performance of the birds and exposure to the same airborne contaminants studied for the cattle. Exposure was associated with fledgling growth. Weakening of the immune systems of the birds was also not associated with exposure, with one exception that had limited biological importance.

The $17-million study was prompted by concerns on the part of government and nongoverment organizations, and the public at large, as well as the oil and gas industry and the cattle producers about the possible effects of petroleum industry facility emissions on animal health.

The concept of the study was launched in 1999 by the governments of the four western provinces, it led to the establishment of the Western Interprovincial Scientific Studies Association (WISSA), a federally incorporated, not-for-profit organization, to manage and oversee the study. One of WISSA's roles was to avoid potential bias from industry, government, and interest groups, and thus ensure a high degree of public and scientific credibility.

WISSA's Board of Directors consists of appointees from each of the western provinces. The Board was assisted in technical matters by a Science Advisory Panel drawn from experts in the fields of research of the study. The Science Advisory Panel, which ensured the scientific integrity and objectivity of the study, advised the researchers on study design, provided scientific guidance to the researchers and the Board of Directors, and helped interpret study findings and their significance.

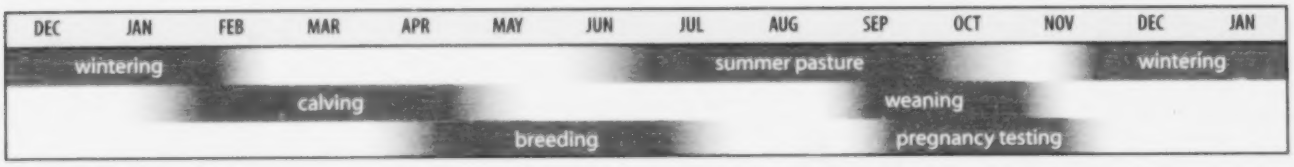
Broad Range of Exposures to Emissions

The 205 herds selected for the study were chosen to ensure a broad range of exposures to different concentrations of airborne contaminants from facilities in major cattle and oil- and gas-producing areas of Western Canada.

Producers were selected for their interest in the study, the availability of herd records, and a working relationship with their local veterinary clinic.

Data on the cows, collected with the help of records kept by the producers, included the results of pregnancy testing, the number of days between calvings for each cow, whether the cow aborted, whether or not the calf died at birth or before it was 3 months old, and whether or not the calf received treatment with a pharmaceutical.

Beef Cattle Production Cycle—Western Canada Herds



Emissions at herd pastures were monitored by a network of monitoring stations, most of them within 1.6 km (1 mile) of the herds. When the cattle moved, the stations were moved monthly with the herds, or new monitoring stations set up as necessary, to collect data on airborne contaminants in locations as close as possible to summer, winter, and calving areas.

The number of oil and gas well sites in a 1.6 km circle around the centre of each pasture was also used as a measure of the exposure of the herds to airborne concentrations of pollutants. No associations were found between the number of surrounding well sites and any measure of animal health or productivity.

Research was directed by two principal investigators at the University of Saskatchewan: Dr. Cheryl Waldner, Western College of Veterinary Medicine, and Dr. Mark Wickstrom, Toxicology Centre. They were assisted by three graduate students, six veterinarians employed by the university, and private veterinarians from more than 60 clinics that provided veterinary services to herd owners in the study.

A 20-member team from RWDI Air, Inc. was responsible for air monitoring. Three contract laboratories analysed samplers from the air monitors, and Dr. Igor Burstyn of the University of Alberta analysed the study's air-monitoring data. Dr. Ted Clark, a pathologist certified by the American College of Veterinary Pathologists, completed detailed histological analyses of samples submitted from field postmortem examinations. Dr. Henrik Stryhn of the University of Prince Edward Island provided advice on statistical analyses.

Epidemiological Investigation

The study was an epidemiological investigation that applied advanced statistical techniques to determine whether there were associations between beef cattle health and productivity and emissions from oil and gas industry facilities.

In completing their statistical analyses, researchers also evaluated other factors, ranging from weather to vaccination, that affected the health and productivity of cow-calf herds in the region. Their findings provide a valuable baseline for assessing reproductive performance and the occurrence of disease in western Canadian cow-calf herds.

With completion of the study there is a need to review with stakeholders the depth and extent of its findings and determine the next steps to make further use of the study reports.

Study Stats

The WISSA study was the largest on-farm study of beef cattle health and productivity of this type ever undertaken in North America, in geographical scope, number of farms that took part, and number of animals monitored.

- *Data were recorded on 39,000 animals from 205 herds pastured on more than 3,300 parcels of land in three provinces.*
- *The study area was about 1,450 km (900 miles) across.*
- *The study followed 205 herds through pregnancy testing in 2001, 203 herds through calving in 2002 and 197 through pregnancy testing in 2002.*
- *Chemical analyses of air-monitoring samples included 13,991 measurements of SO_2, 11,447 measurements of VOCs, 7,502 measurements of H_2S, and more than 365 measurements of PM_{10} and PAHs. For SO_2, H_2S and VOCs there was at least 10 % duplicates for quality assurance.*
- *Veterinarians examined 183 aborted fetuses and 1,506 full-term calves that died at birth or in the early stages of life.*
- *For histopathological examinations, veterinarians submitted nearly 30,000 tissues from 180 aborted fetuses, 557 stillborn calves, and 941 live-born calves that died before weaning.*
- *Immune system health studies applied to 325 newborn calves from 60 herds and more than 500 yearlings from 27 herds.*
- *For the bird study, researchers installed 540 starling nest boxes over 2 years. They obtained data on reproductive performance from 264 occupied nests, 1,383 eggs, and 927 nestlings from 268 clutches.*

Study Methods

Selecting the Herds

Cow-calf herds were selected across major cattle and oil- and gas-producing areas of Western Canada, to achieve a wide range of exposures to different concentrations of emissions.

To be included, herds were to be between 50 and 250 breeding females. Producers had to be interested in the study, committed to keeping thorough records on the performance of their herds, and have a working relationship with a local veterinary clinic.

Herds with obvious exposure to emissions from significant sources other than oil and gas facilities, such as very large pulp and paper operations, coal-fired power plants, and intensive livestock operations were not considered.

Herds were selected to maximize the range of exposures available for study. Based on information from herd owners, the estimated potential for exposure was considered high in 92 herds, moderate to low in 71 herds and very low to no exposure in 42 herds.

Collecting Herd Data

Information on performance and health of the cattle as well as other factors that could affect herd productivity was collected by a veterinarian employed by the research study. The data were collected during regular herd visits and using records supplied by the herd owner and reports from the local veterinarian.

Distances of herds from facilities

The following table describes the percentage of cows in the calf mortality and treatment studies that were exposed to a facility at least once during the study period.

Distance from Facility	Prenatal period	Last trimester
within 1 mile of a well site	72%	64%
within 1 mile of a battery site	37%	25%
within 5 miles of a gas plant or gas-gathering facility	69%	63%

Productivity Data

For each cow veterinarians recorded the following:

- pregnancy status
- abortion
- calving-to-calving interval (the number of days between calvings for each cow)
- breeding-to-calving interval (the number of days between the time when the bull was first put in with the cows to the date when the cows calved)
- stillbirth (a calf dead within 1 hour after birth)
- calf death (a calf that died more than 1 hour after birth)
- calf treatment (a calf receiving any pharmaceutical for therapeutic or prophylactic indications).

Also collected were data on cow age, breed, body condition, vaccination status, herd breeding and calving management, and other factors that could influence findings, such as the weather, vegetation, soil types, and landforms where the herds were pastured.

Location Data

The location of each cow for each month of the study was determined from herd records and used by study personnel to evaluate the exposure status of each cow.

Information on the locations of more than 39,000 animals from 205 herds on more than 3,300 different parcels of land was recorded for each half-month interval from April 2001 to December 2002. The result was a total of 3.7 million animal locations.

Immunological Data

Veterinarians collected samples of blood from selected yearlings and calves, and inoculated the yearlings with a rabies vaccine. Concentrations of antibodies in samples collected before and after vaccination, and numbers of white blood cells in the samples, were compared for animals exposed to varying concentrations of airborne contaminants to determine potential associations between exposure and immune system health.

The veterinarians examined the carcasses of 94% of calves that died, 72% of stillbirths, and 35% of aborted fetuses. They

Herd selection criteria included the requirement that all animals were to be individually identified with at least one ear tag.

reported the results of their gross postmortem examinations, and collected tissue samples for laboratory analysis.

Monitoring Emissions

The study used monitoring stations to measure concentrations of airborne contaminants near the cattle. Stations were placed on or as close as possible to all pastures used by the cattle during each month of the study.

Stations measured the following types of oil and gas industry emissions:

- SO_2, to represent combustion emissions associated with sour-gas flaring and the operation of sulphur recovery plants
- H_2S, to represent incomplete combustion and fugitive emissions from sour-gas collection and processing facilities
- VOCs (volatile organic compounds) to represent fugitive, dehydrator, and incomplete combustion emissions. Benzene and toluene concentrations were examined as a marker for the larger group of measured VOC compounds.
- $PM_{1.0}$ (fine particulate matter with an aerodynamic diameter of 1.0 µm or less), to represent incomplete combustion from sweet- and sour-gas combustion processes
- PAHs (polycyclic aromatic hydrocarbons), to represent incomplete combustion from sweet- and sour-gas combustion processes
- metals, as they have often been associated with combustion emission sources.

Two types of air monitors were used to measure concentrations of airborne contaminants. One was the passive type, in which air moves across a sampler or diffusion membrane. It measured concentrations of SO_2, H_2S, and 26 VOCs. The other was the active type, in which a solar-charged electric pump draws air through a filter, and a filter plus a column filled with absorbent material. It measured concentrations of $PM_{1.0}$, 30 PAHs, and 14 metals.

Air-monitoring began in April 2001 and was completed in January 2003. SO_2, H_2S, and VOCs were measured for all study herds from April 2001 to June 2002, and for a subset of 50 herds from July 2002 to December 2002. $PM_{1.0}$, PAHs, and metals were measured for a subset of 32 study herds, from January 2002 to January 2003.

Passive samplers and the collectors from the pump-operated monitors were installed, then retrieved and replaced each month, by a team of 15 technicians. Exposed samples and collectors were shipped to contract laboratories for analysis.

The technicians moved each passive monitor,or installed additional monitors, as necessary at the end of each calendar month to ensure that there was a monitor at or near each location with cattle at all times during the study.

Active monitors remained in position at a central location within the wintering and calving grounds of 32 study herds.

Data were obtained from monitors at more than 1,200 locations across the major oil- and gas-producing areas of Western Canada.

At the conclusion of air monitoring all air monitoring data were examined to evaluate data quality and whether or not the air-concentration measurements of selected contaminants could be related to facility locations and emissions. The results showed measured concentrations were associated with available regulatory data from surrounding oil and gas field facilities.

Determining Exposure

The study used two methods of determining exposure of the cattle (and birds) to airborne contaminants: concentrations measured by the air-monitoring stations and the "density" of surrounding oil and gas well sites.

Air Monitors

The exposure of each cow on each quarter section to each airborne contaminant was determined from the mean monthly concentration of that contaminant measured by all air-monitoring stations within 1.6 km of the centre of the quarter section or by the nearest available air-monitoring station.

Where cattle had access to more than one quarter section during a month, the values of the concentrations measured by the stations for each quarter section were averaged for that month.

To determine the exposure of each animal over a biologically important period, such as gestation, for example, mean monthly concentrations were averaged over the appropriate months to arrive at a cumulative exposure for that period for each animal.

Monitoring station for sampling SO_2 and H_2S, and VOCs. Inset shows field installation, without protective surrounding fence, of a monitoring station for sampling PM1.0, PAHs, and metals.

The air-monitoring program sought to place a monitor on or as close as possible to pastures and calving or wintering areas used by the cattle for each month of the study.

Density of Surrounding Oil and Gas Wells

The number of oil and gas well sites within a circle with radius of 1.6 km, and centred on each quarter section used by the cattle, was converted to a figure for the "density" of surrounding facilities. Values for well-site density were then used as a measure of exposure of the animals to all potential emissions from these facilities.

Studying the Starlings

The study included research on the potential effects of emissions on the reproductive performance and immune system health of the European starling, a wildlife species that shared the same environment as the cattle.

European starlings were chosen to complement research on the cattle because they have been used as indicators of environmental contamination in previous studies. Their use was particularly appropriate because passerine birds are more sensitive to most inhaled toxicants than mammals, as a result of the unique anatomy and physiology of their respiratory system.

The reproductive performance and immune system health of the birds was measured in breeding starlings that occupied 30 nest boxes in 2001 and 24 in 2002, on cow-calf operations studied. Nesting sites, in a band across central Alberta and Saskatchewan, represented a wide range of potential exposures.

Monthly mean concentrations of airborne SO_2, H_2S (2002 only), and VOCs at the nest boxes were obtained from nearby air monitors used in the cattle study. If there was more than one monitor within 1.6 km of the nest box, an average concentration was used. If there were no monitors within 1.6 km, concentration data from the nearest monitor were used.

Analysing the Data

The researchers used mixed effects models, a type of statistical analysis, to determine whether there were associations between emissions and various measures of animal health and productivity.

The models described the relationship between exposure and effects, how strongly the effects were associated with the amount of exposure, and how likely it was that the effect was not due to chance.

In addition, the models accounted for factors that could distort results, such as the weather, the geographic region where the herds were pastured, age and breed of the cow, body condition score, whether the cow was purchased or born on farm, vaccination status, month of pregnancy, and the possibility of similarities among cows in the same herd.

For example, in preliminary analyses it might appear that higher levels of airborne SO_2 were associated with fewer stillbirths. But what if, in that situation, higher levels of SO_2 happened to coincide with areas less affected by drought? Models were developed to differentiate the effects of other factors from the primary exposures of interest.

Biologically Relevant Periods

Associations were examined for exposure measured during "at risk" periods or intervals considered biologically relevant to the outcome studied.

In studies of calf mortality, for example, researchers investigated possible associations during three at-risk periods: *in utero* exposure of the calves throughout pregnancy of the cows, *in utero* exposure during the last three months of pregnancy, and direct exposure of the calves during their first month of life.

Factors Other Than Emissions

The study also provided an opportunity to examine other factors that could affect herd health and productivity.

For example, cows vaccinated with a modified live vaccine were on average 1.5 times less likely to abort than cows that were not vaccinated. In addition, cows thin at pregnancy testing, and those pregnant with twins, were more likely to abort than other cows.

Calves born to cows from areas most affected by the drought in 2001 were more likely to be stillborn and calves born on the coldest days of the calving season were more likely to die before 3 months of age.

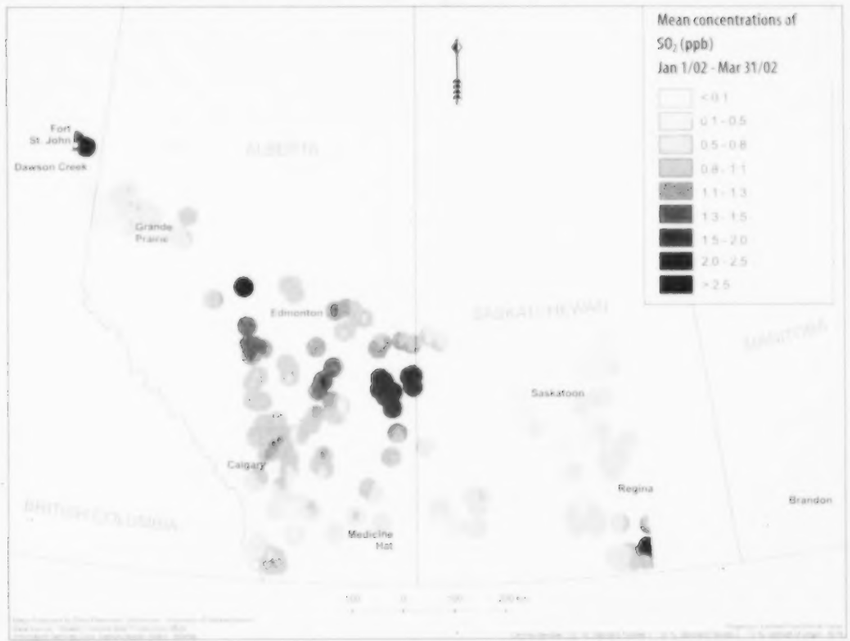
Veterinarians took samples of whole blood from the jugular veins of selected yearlings and calves. The blood was analysed for the presence of antibodies and numbers of white blood cells, as part of investigations on exposure and immune system health.

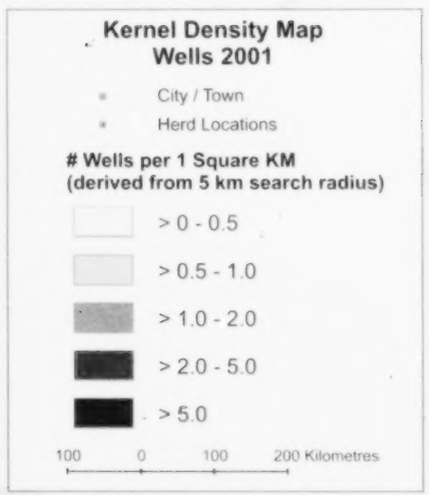
Researchers identified other factors, such as extreme weather conditions and vaccination practices, that affected animal health and productivity. These other factors were corrected for when analysing the impact of oil and gas exposure.

HERD LOCATIONS FOR 2001 AND 2002 IN RELATION TO OIL AND GAS WELL SITES IN 2001, SHOWING A BROAD DISTRIBUTION OF HERDS AND WELLS IN AREAS OF NO, MODERATE, AND HIGH PETROLEUM INDUSTRY ACTIVITY

Well sites, with flare in the background. No associations were found between any animal health and productivity factor studied and industry emissions when numbers of well sites around pastures were used as a way to measure exposure of the animals.

Mean concentrations of SO_2, measured in ppb by monitoring stations at pastures across the study area, from January 1, 2002 to March 31, 2002





Note: Cattle were placed on the pastures in Manitoba near the end of the study after the completion of calving season in 2002. Air quality was not measured at these sites.

Study Milestones

1999	• Deputy Ministers of Environment from the western provinces identifed the need • Intergovernmental Ad Hoc Committee struck • Co-chairs of the Science Advisory Panel (SAP) chosen
2000	• First study plan developed • Western Interprovincial Scientific Studies Association (WISSA) established • Responsibility for the study transferred from Ad Hoc Committee to WISSA Board of Directors • SAP members appointed • Team at University of Saskatchewan designed study • SAP reviewed and refined detailed study design
2001 - 2002	• Cattle monitored, starting in breeding season • Air monitoring by RWDI AIR Inc., Calgary, AB (RWDI) began • Field work by team at University of Saskatchewan • SAP provided oversight and quality assurance
2002 -2003	•Calving season data collected • Air monitoring continued • SAP provided oversight and quality assurance
2003 - 2004	• Data analysis and evaluation, and statistical analyses, carried out by team at University of Saskatchewan • SAP reviewed results of analyses, proposed further refinements, and provided quality assurance • Additional analyses of exposure data, proposed by SAP, conducted by RWDI and University of Alberta
2005	• Research appendices prepared by team at University of Saskatchewan, University of Alberta and RWDI • SAP reviewed findings with researchers and provided oversight and interpretive guidance
2006	• Preparation of research appendices continued • WISSA public report completed and released

Glossary

abomasal - relating to the fourth compartment of the stomach in cattle

B-cell or B-lymphocyte - a type of white blood cell that plays a major role in humoral immunity

bursa of Fabricius - a lymphoid gland in birds, the site of B-cell maturation

colitis - inflammation of the colon

disseminated intravascular coagulation - widespread blood clotting within the vessels

dystocia - difficulty in giving birth

enteritis - inflammation of the intestine

epidemiology - study of factors determining the frequency and distribution of diseases

H_2S - hydrogen sulphide

heterophil - a granular type of white blood cell in birds

histopathology - microscopic examination of diseased or damaged tissue

in utero - in the uterus

lymphocyte - a type of white blood cell, part of the immune system

myopathy - muscle damage

PAHs - (polycyclic aromatic hydrocarbons) chemicals with several carbon rings

phenolics - a class of organic chemicals often found as contaminants in water

PM_{10} - particulate matter, particulates with an aerodynamic diameter of 10 µm or less

SAP - Science Advisory Panel

SO_2 - sulphur dioxide

sour gas - natural gas containing sulphur compounds, also called acid gas

suppurative bronchopneumonia - a type of lung inflammation

tarsometatarsal bone - the lowest part of a bird's leg above the toes, usually without feathers

T-cell or T-lymphocyte - a type of white blood cell with a major role in cell-mediated immunity

VOCs - volatile organic compounds

WISSA - Western Interprovincial Scientific Studies Association

Study Findings

Study highlights are presented below. For a more detailed discussion of findings, consult the Technical Summary or the reports in the Research Appendices which form the bulk of WISSA's public report.

CATTLE PRODUCTIVITY

Nonpregnancy and Breeding to Calving Interval

Are cows more exposed to emissions less likely to get pregnant or have a longer delay between calvings resulting in later born, smaller calves? Both factors are key measures of fertility, which affects the profitability of cow-calf operations.

Data on emissions of SO_2, benzene, and toluene were analysed for 32,871 cows in 205 herds for the 2001 breeding season. Data on the same emissions, as well as H_2S, were analysed for 9,068 cows from 49 of the herds for the 2002 breeding season.

Nonpregnancy

Cows exposed to the highest measured concentrations of the four airborne contaminants were just as likely to be pregnant as those that were less exposed.

Time to Calving

Cows more exposed to benzene were more likely to have a longer delay from first bull contact to calving, as determined from the date when the bull was first put in with the cows to the date when the cows calved. For an average cow exposed to the highest 25% of benzene concentrations, compared with an average cow exposed to the lowest 25% of concentrations, this period was 3 days longer.

Abortion and Stillbirth

Are pregnant cows with greater exposure to SO_2, H_2S, benzene, and toluene more likely to abort or to deliver stillborn calves?

Data on emissions were analysed for 28,144 cows followed from the beginning of the breeding season in 2001 through calving in 2002.

On average, 1.6% of the cows aborted their calves. Of the

KEY FINDINGS

Within the range of exposures measured during the study:

- Exposure to emissions was not associated with nonpregnancy, abortion and stillbirth.
- A small increase in the time from first bull contact to calving was associated with exposure to benzene.
- A small increase in calf deaths was associated with exposure to the highest concentrations of SO_2.
- Increased frequency of calves receiving treatment was associated with exposure to H_2S.
- Some measures of exposure to VOCs were associated with changes to the immune system and lesions to respiratory tissue in cattle.
- Exposure to emissions was not associated with most measures of starling reproduction and immune system health.

Respiratory System

Calves more exposed to benzene and toluene, and that died after they were more than 3 weeks old, were slightly more likely to have lesions in their respiratory system.

Thyroid Gland and Skeletal or Cardiac Muscle

Calves whose dams were more exposed to SO_2 during gestation were slightly more likely to develop lesions in their skeletal and cardiac muscle. Calves whose dams were more exposed to benzene during gestation were slightly more likely to develop lesions in their thyroid glands.

CATTLE HEALTH

Yearling Immune System Health and SO_2, H_2S, Benzene, and Toluene

Does exposure to higher concentrations of airborne emissions of SO_2, H_2S, benzene, and toluene weaken the immune systems of yearling cattle?

Immune system health was assessed by testing blood samples collected from more than 500 yearlings in 27 mixed-breed herds in Alberta and Saskatchewan in spring 2002. Samples were tested for antibody production in response to rabies vaccination, and for concentrations of white blood cells (B-lymphocytes and four T-lymphocyte subtypes (CD4, CD8, γδ, and WC1) that play critical roles in the response of the immune system to infection.

Antibody Production

There was no decrease in the antibody response to vaccination in the yearlings most exposed to emissions.

Starling nest boxes in Alberta and Saskatchewan in 2001. Each open circle represents one of 30 farms where nest boxes were installed. Each farm had 10 nest boxes, for a total of 300 boxes.

BIRD STUDY

Reproductive Performance of European Starlings

Was the reproductive performance of European starlings (Sturnus vulgaris) lower where the birds were exposed to higher concentrations of airborne SO_2, H_2S, benzene, and toluene?

European starlings were chosen to complement research on the cattle because they have been used as indicators of environmental contamination in previous studies.

Reproductive performance of the birds was assessed by measuring their hatching and fledging success, and nestling growth. Nest boxes were installed in suitable locations near air-monitoring stations on 30 of the 205 cattle operations taking part in the study. Breeding starlings occupied 136 of the boxes in 2001 and 128 in 2002.

Hatching and fledging failure, nestling weight, egg

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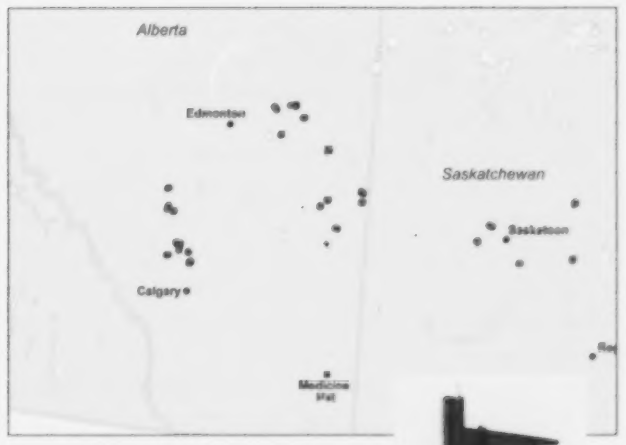

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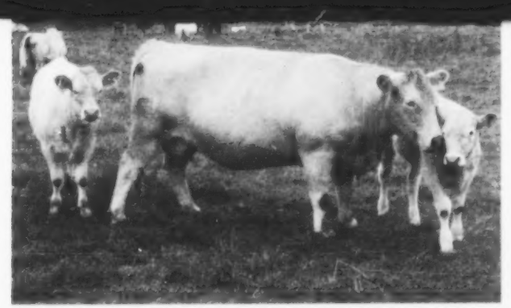
Animal Health Effects
Associated with Exposure to Emissions from Oil- and Gas-Field Facilities

association not found | association found | association not studied

	SO_2	H_2S	VOCs as benzene	VOCs as toluene	PAHs	PM_{10}	Well-Site Density
Associations Addressing PRIMARY STUDY HYPOTHESES—CATTLE							
Greater risk of non-pregnancy [RA 6]	■		■	■			■
Longer breeding-to-calving interval [RA 6]	■		■	■			■
Greater risk of abortion* [RA 7]	■	■	■	■			■
Greater risk of stillbirth* [RA 7]	■	■	■	■			■
Greater risk of mortality in calves < 3 months old (prenatal exposure - first bull exposure to calving date) [RA 8]	■		■	■			■
Greater risk of mortality in calves < 3 months old (their dams exposed last trimester) [RA 8]	■	■	■	■			■
Greater risk of mortality in calves < 3 months old (exposure during 1st month) [RA 8]	■	■	■	■			■
Associations Addressing SECONDARY STUDY HYPOTHESES—CATTLE							
Greater risk of lesions with pre- and postnatal exposure—calf immune systems [RA 10]	■		■	■			■
Greater risk of lesions with pre- and postnatal exposure—calf nervous systems [RA 10]	■		■	■			■
Greater risk of lesions with postnatal exposure only—calf immune systems [RA 10]	■	■	■	■			■
Greater risk of lesions with postnatal exposure only—calf nervous systems [RA 10]	■	■	■	■			■
Greater risk of lesions with postnatal exposure only—calf respiratory systems [RA 10]	■	■	■	■			■
Lower count of B-cells in yearling cattle immune systems [RA 11&12]	■	■	■	■	■	■	■
Lower count of CD4 T-cells in yearling cattle immune systems [RA 11&12]	■	■	■	■	■	■	■
Lower count of CD8 T-cells in yearling cattle immune systems [RA 11&12]	■	■	■	■	■	■	■
Lower count of γδ T-cells in yearling cattle immune systems [RA 11&12]	■	■	■	■	■	■	■
Lower count of WC1 T-cells in yearling cattle immune systems [RA 11&12]	■	■	■	■	■	■	■
Lower response to vaccine in yearling cattle immune systems [RA 11&12]	■	■	■	■	■	■	■
Lower count of B-cells—calf immune system health [RA 13]	■		■	■			■
Lower count of CD4 T-cells—calf immune system health [RA 13]	■		■	■			■
Lower count of CD8 T-cells—calf immune system health [RA 13]	■		■	■			■
Lower count of γδ T-cells—calf immune system health [RA 13]	■		■	■			■
Lower count of WC1 T-cells—calf immune system health [RA 13]	■		■	■			■
Associations Addressing OTHER STUDY HYPOTHESES							
Greater risk of cow disposal (includes culling or death loss) [RA 6]	■		■	■			■
Greater risk of calves receiving treatment < 3 months old (prenatal exposure) [RA 8]	■		■	■			■
Greater risk of calves receiving treatment < 3 months old (dams exposed last trimester) [RA 8]	■	■	■	■			■
Greater risk of calves receiving treatment after first month (postnatal exposure) [RA 8]	■	■	■	■			■
Greater risk of lesions with pre- and postnatal exposure—calf skeletal or cardiac muscle [RA 10]	■		■	■			■
Greater risk of lesions with pre- and postnatal exposure—calf thyroid glands [RA 10]	■		■	■			■
Greater risk of lesions with postnatal exposure only—calf skeletal or cardiac muscle [RA 10]	■	■	■	■			■
Associations Addressing SECONDARY STUDY HYPOTHESES—AVIAN							
Lower hatching success [RA 14]	■	■	■	■			■
Lower fledging success [RA 14]	■	■	■	■			■
Shorter tarsal length [RA 14]	■	■	■	■			■
Shorter first primary feather [RA 14]	■	■	■	■			■
Lower IgM antibody production [RA 15]	■		■	■			■
Smaller spleen [RA 15]	■	■	■	■			■
Smaller bursa of Fabricius [RA 15]	■	■	■	■			■
Lower IgY antibody production [RA 15]	■	■	■	■			■
Lower T-cell response to phytohemagglutinin [RA 15]	■	■	■	■			■
Higher heterophil/lymphocyte (H/L) ratios [RA 15]	■	■	■	■			■

RA refers to the applicable research appendix in the *Research Appendices*
* H_2S was not monitored before September 2001.

Associations vs. Effects



Abortion and Stillbirth

Are pregnant cows with greater exposure to SO_2, H_2S, benzene, and toluene more likely to abort or to deliver stillborn calves?

Data on emissions were analysed for 28,144 cows followed from the beginning of the breeding season in 2001 through calving in 2002.

On average, 1.6% of the cows aborted their calves. Of the 28,402 full-term calves born, an average of 2.6% were stillborn. These values are similar to averages for abortions and stillbirths reported for other beef cattle herds in Western Canada.

Exposure to the highest measured concentrations of emissions from the oil and gas industry during pregnancy was not associated with more abortions and stillbirths.

Calf Mortality and Treatment

Are calves more likely to die or be treated, if they or their dams are more exposed to emissions? A treatment event occured when the producer reported that the calf was given a pharmaceutical product for the treatment of an observed illness or, less frequently, to prevent a perceived disease threat.

Data on emissions were analysed for 27,511 calves born to cows in 203 herds followed from the beginning of the breeding season in 2001 through calving in 2002.

Calf Mortality

Cows exposed to the highest concentrations of SO_2 during their last three months of pregnancy (as well as throughout their pregnancy) were more likely to deliver calves that died before they were 3 months old.

For example, on average, 4.1% of male calves born to replacement heifers on a warm day in March (temperature was 0°C) would be likely to die before 3 months of age if their dams were exposed to the lowest measured concentrations of SO_2 (less than 0.3 parts per billion). However, if their dams were exposed to the highest measured concentrations of SO_2 (more than 1.5 parts per billion), 5.9% of the male calves born under the same conditions would be likely to die—an increase of 1.8%.

Treatment

Greater exposure of the calves to H_2S in their first month of life was associated with a 2% increase in the number calves that received treatment after the first month, before they were turned out onto summer pasture. This was the only association between H_2S exposure and a health outcome identified in the study.

In conclusion, exposure to some emissions from oil and gas facilities was associated with calves being slightly more likely to die in the first few months of life and a slightly higher percentage of calves receiving treatment with pharmaceuticals.

Most common causes of the death of calves (%)

183 aborted fetuses		560 stillborn carcasses		388 newborn carcasses		558 carcasses >3 days old	
unknown	48.1	unknown	32.3	heart failure	12.6	primary or secondary starvation	19.7
placental infection	13.1	dystocia	30.2	unknown	10.8	abomasal ulcer, torsion/ perforation	15.4
cow death before birth	9.3	thyroid gland malfunction	12.7	dystocia	8.2	enteritis/ colitis	9.5
heart failure	8.2	heart failure	10.7	thyroid gland malfunction	7.7	heart failure	5.9
thyroid gland malfunction	8.2	congenital anomaly	2.9	generalized bacterial infection	7.5	unknown	5.7
congenital anomaly	3.8	hemosiderosis	2.5	trauma	7.2	generalized bacterial infection	5.6
disseminated intravascular coagulation	1.6	placental infection	1.6	pneumonia	5.4	intestinal accident	5.2
		skeletal myopathy	1.4	skeletal myopathy	4.6	pneumonia	4.1

Note: In addition to these common causes of death, there were numerous other causes that affected only a small percentage of calves. As a result, the percentages do not total 100.

Causes of Calf Mortality

Samples were tested for antibody production in response to rabies vaccination, and for concentrations of white blood cells (B-lymphocytes and four T-lymphocyte subtypes (CD4, CD8, γδ, and WC1) that play critical roles in the response of the immune system to infection.

Antibody Production

There was no decrease in the antibody response to vaccination in the yearlings most exposed to emissions.

White Blood Cells

Yearlings more exposed to toluene (> 0.82 µg/m^3; highest 25%) had an average of 30% fewer CD4 T-lymphocytes in their blood than yearlings less exposed (< 0.41 µg/m^3; lowest 25%).

The findings suggest that exposure to emissions from oil and gas facilities could alter the immune systems of beef cattle; however, the biological significance of the alterations is unclear.

Yearling Immune System Health and $PM_{1.0}$, PAHs, and Metals

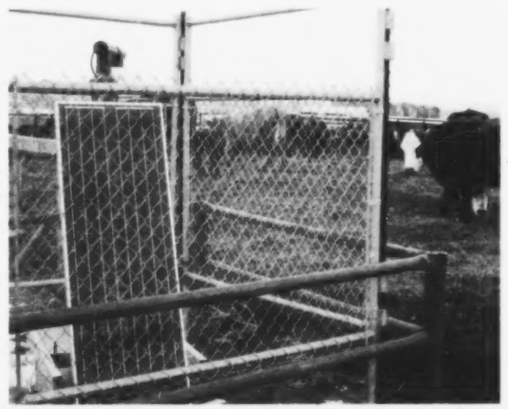
Does exposure to higher concentrations of airborne emissions of fine particulate matter ($PM_{1.0}$), polycyclic aromatic hydrocarbons (PAHs), and metals weaken the immune systems of yearling cattle?

As in the previous investigation, effects on immune system health were assessed by testing blood samples collected from 469 yearlings in 22 mixed-breed herds in Alberta and Saskatchewan in spring 2002. The 22 herds were selected from the 27 in the previous investigation where particulate monitors were located.

Samples were tested for antibody production and concentrations of white blood cells, as in the previous investigation.

No associations were found between airborne concentrations of $PM_{1.0}$ or PAH_s and white blood cell counts or antibody production in response to rabies vaccination.

Airborne concentrations of metals were below detection limits in most herds and therefore the potential effects of exposure were not examined.



Air monitor for sampling particulate matter, shown with surrounding protective fencing

on the cattle because they have been used as indicators of environmental contamination in previous studies.

Reproductive performance of the birds was assessed by measuring their hatching and fledging success, and nestling growth. Nest boxes were installed in suitable locations near air-monitoring stations on 30 of the 205 cattle operations taking part in the study. Breeding starlings occupied 136 of the boxes in 2001 and 128 in 2002.

Hatching and fledging failure, nestling weight, egg weight, and egg volume were not significantly associated with increasing exposure to any of the measured emissions.

Nestling size, based on the length of the tarsometatarsal bone, decreased significantly with increasing exposure to benzene and toluene in 2002. The length was not measured in 2001. Bone length was 7.1% shorter in cases of nestlings exposed to the upper ranges of benzene and 8.1% shorter for toluene, compared with average bone length. The significance of this finding on fledging fitness and ability to survive is uncertain.

Apart from this association, the reproductive performance of starlings did not decline when the birds were more exposed to airborne contaminants.

Starling Immune System Health

Did exposure to greater concentrations of airborne SO_2, H_2S, benzene, and toluene weaken the immune systems of starlings?

Changes in immune system health were assessed in the same group of starlings studied for their reproductive success.

In 2001, researchers measured:

- concentrations of antibodies in blood in response to injections of sheep red blood cells
- response of white blood cells to injections in the skin of substances that stimulate the immune response
- weights of some lymphoid organs.

In 2002 they also:

- measured immune response to injection of bovine serum albumin under the skin
- evaluated tissues from immune organs under the microscope.

No significant associations were found between exposures to airborne emissions and any of the immune system health measures, with one exception. In 2002, researchers observed a change in the relative numbers of two types of white blood cells, an indication of stress in some birds.

The significance of this finding to nestling immune system health is likely to be minimal.

OTHER STUDIES

Water Quality Testing

Samples of drinking water for 53 study herds, collected by the veterinarians in winter 2001/02, were analysed for

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Higher heterophil/lymphocyte (H/L) ratios [RA 15]	

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Associations vs. Effects

This epidemiological investigation examined data collected from privately owned cow-calf operations as well as the results of laboratory analyses of biological samples and samplers from air monitors. Advanced statistical techniques were used to determine whether there were associations between emissions from oil and gas industry facilities and measures of beef cattle and wild bird health and productivity.

This was an observational study that depended on data collected in the real world where conditions were not controlled by the researchers. Researchers used the observation data collected to examine the association between exposure to emissions and animal health outcomes. Statistical methods were used to determine the strength of the association between exposure and animal health and whether the association was statistically significant. The study reported some evidence suggesting potential causal associations between some types of emissions and animal health outcomes and also strong evidence suggesting there were no associations between measured emissions and other types of outcomes.

The presence of an association alone does not prove that emissions caused a change in animal health. For example, in cases where there was a statistically significant association between an effect (increased risk of mortality) and exposure (SO_2), the researchers could conclude, that a higher frequency of calf deaths were associated with exposure to higher levels of SO_2, not necessarily that more deaths were caused by higher exposure to SO_2. In this example, the observed increase in the frequency of calf mortalities with increasing exposure was also an important finding. A consistent increase in effect with increasing exposure, especially if it was observed with supporting evidence from other studies provides further evidence that the association might reflect a true cause-and-effect relationship.

On the other hand, where a carefully designed and adequately sized observational study such as this does not demonstrate an association, this "negative finding" helps rule out a cause-and-effect relationship as it relates to the range of exposures observed within the study. For several important study questions, there was no association between exposure to emissions and the specified outcome. For example, there were no associations between exposure to emissions across the measured range of exposures and the frequency of nonpregnancy, abortions or stillbirths. The large number of herds and animals included in the study and the ability of the study to detect a difference of less than 2% in the case of calf mortality indicates that it is unlikely that the study would have missed an association had there in fact been one.

Therefore, the finding that there were no associations between exposure to emissions and frequency of nonpregnancy, abortion or stillbirth has a high degree of confidence attached to it.

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malfunction		anomaly		infection			
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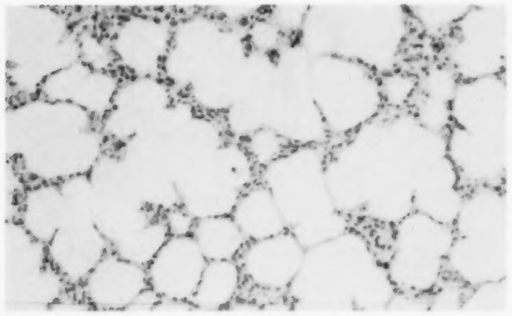
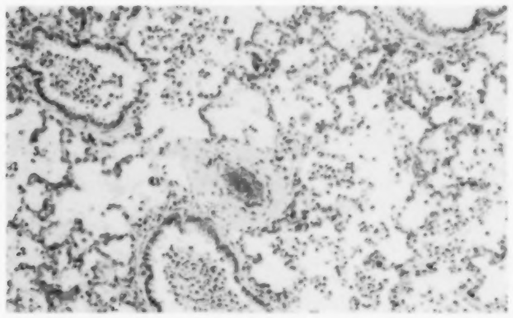
Note: In addition to these common causes of death, there were numerous other causes that affected only a small percentage of calves. As a result, the percentages do not total 100.



Normal lung tissue, live newborn calf



Acute suppurative bacterial bronchopneumonia, 28-day-old calf

Greater exposure of the calves to H_2S in their first month of life was associated with a 2% increase in the number calves that received treatment after the first month, before they were turned out onto summer pasture. This was the only association between H_2S exposure and a health outcome identified in the study.

In conclusion, exposure to some emissions from oil and gas facilities was associated with calves being slightly more likely to die in the first few months of life and a slightly higher percentage of calves receiving treatment with pharmaceuticals.

Causes of Calf Mortality

Herd veterinarians conducted postmortem examinations on 94% of the calves that died, 72% of the stillbirths and 35% of the aborted fetuses from the 2002 calf crop that died before the end of May.

They also collected standard sets of tissue samples from the carcasses. The tissues were sent to a pathology lab and examined for microscopic changes by a pathologist.

Results were used to determine the immediate cause of death of the animals, and to support follow-up work, described in the next part of the study, on assessing potential associations between exposure and the likelihood of lesions developing in tissues.

Lesions in Calf Tissue

Are calves more likely to develop lesions in their tissues if they or their dams are more exposed to emissions? Lesions are tissue abnormalities caused by disease or trauma.

Tissue samples were collected from the immune, nervous, and respiratory systems, as well as the thyroid glands and skeletal and cardiac muscle of 1,531 aborted fetuses, stillbirths, and calf mortalities with exposure data from the 2002 calf crop.

Immune and Nervous Systems

Calves more exposed to SO_2, H_2S, benzene, and toluene were not more likely to develop lesions in their immune or nervous systems.

Air monitor for sampling particulate matter, shown with surrounding protective fencing

Calf Immune System Health

Were pregnant cows exposed to higher concentrations of SO_2, benzene, and toluene more likely to give birth to calves with weakened immune systems?

The immune systems of young calves continue to develop after birth, leaving them at a relatively increased risk of contracting an infectious disease during the first weeks of life. Effects on the immune system health of the calves were assessed by testing blood samples collected from 325 calves from 60 study herds in Alberta and Saskatchewan in spring 2002. Most of the calves sampled were between 3 and 8 days of age.

Samples were tested for concentrations of white blood cells, as in the yearling immune system health studies.

In calves exposed to benzene at concentrations ≥0.38 µg/m^3 (highest 25%) compared with calves exposed to concentrations < 0.28 µg/m^3 (lowest 25%), numbers of CD4 T-lymphocytes averaged 40% lower and numbers of CD8 T-lymphocytes averaged 43% lower.

Similarly, in calves exposed to toluene at concentrations ≥ 0.71 µg/m^3 (highest 25%) compared with calves exposed to concentrations < 0.35 µg/m^3 (lowest 25%), numbers of CD4 T-lymphocytes were 40% lower.

Results suggest that exposure to emissions from oil and gas facilities could alter the immune systems of newborn calves; however, the biological significance of the alterations is unclear.

cells, an indication of stress in some birds.

The significance of this finding to nestling immune system health is likely to be minimal.

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Water Quality Testing

Samples of drinking water for 53 study herds, collected by the veterinarians in winter 2001/02, were analysed for pesticides, soil sterilants, insecticides, volatile organic compounds, phenolics, and other substances.

Concentrations of volatile organic compounds, soil sterilants, and herbicides were undetectable in almost all samples. In a few samples, concentrations of metals such as iron slightly exceeded drinking water standards for livestock.

There were no indications of contamination by the oil and gas industry.

Feeding Management and Forage Testing

Because of the possibility that nutritional management and forage quality could have had an effect on the health of calves and therefore study findings, herd feeding practices and forage quality were examined in spring 2002.

Analyses of 501 samples from the remaining winter supply of forage for 159 study herds showed that much of the forage would require supplementation to meet the requirements of an average beef cow in early lactation. Nutritional management practices reported during herd visits in spring 2002 showed that producers are aware of the most common feed deficiencies and use some type of ration supplementation.

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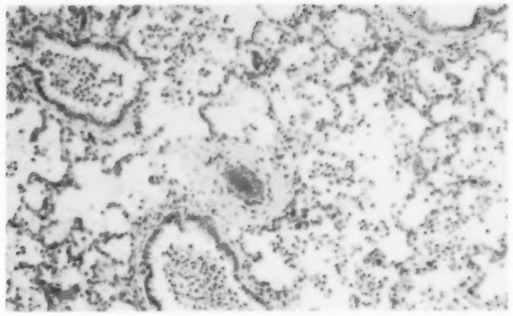

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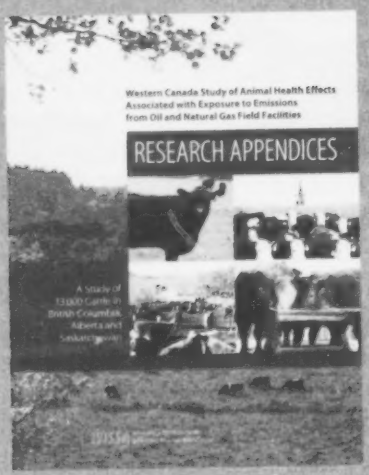
PUBLIC REPORT

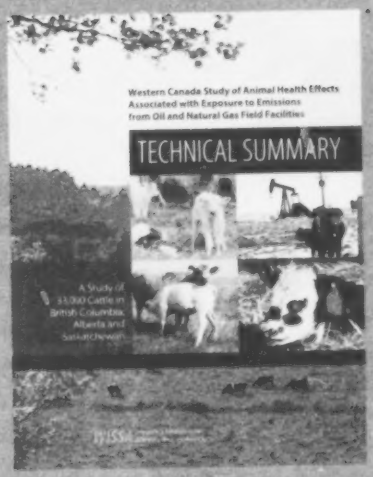
The public report of the Western Interprovincial Scientific Studies Association (WISSA) presents the results of the Western Canada Study of Animal Health Effects Associated with Exposure to Emissions from Oil and Natural Gas Field Facilities.

"What About the Cattle?" presents the highlights of the study. It is one of four publications that comprise the public report.

The others are as follows:


Western Canada Study of Animal Health Effects
Associated with Exposure to Emissions
from Oil and Natural Gas Field Facilities
RESEARCH APPENDICES

Research Appendices
A collection of 17 research appendices that presents the details of all research for the study


Western Canada Study of Animal Health Effects
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TECHNICAL SUMMARY

Technical Summary
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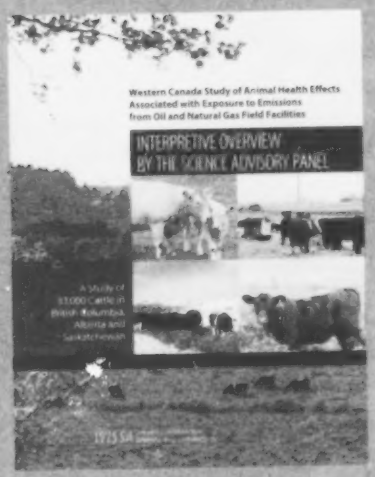
Western Canada Study of Animal Health Effects
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INTERPRETIVE OVERVIEW
BY THE SCIENCE ADVISORY PANEL

The Interpretive Overview by the Science Advisory Panel
The views of the Science Advisory Panel on the interpretation and significance of the study findings

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